

## Solutions Network Formulation Report

# NASA's Potential Contributions for Using Solar Ultraviolet Radiation in Conjunction with Photocatalysis for Urban Air Pollution Mitigation and Increasing Air Quality

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### 1. Candidate Solution Constituents

- a. Title: NASA's Potential Contributions for Using Solar Ultraviolet Radiation in Conjunction with Photocatalysis for Urban Air Pollution Mitigation and Increasing Air Quality
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- c. Identified Partners: U.S. Environmental Protection Agency and U.S. Department of Energy's Lawrence Berkeley National Laboratory
- d. Specific DST/DSS: U.S. Environmental Protection Agency's Air Quality Index
- e. Alignment with National Application: Air Quality and Public Health
- f. NASA Research Results – Table 1:

Missions	Sensors/Models	Data Product
Heritage Nimbus 7 and Meteor 3, Earth Probe	Total Ozone Mapping Spectrometer	Aerosol & Ozone
Aura	OMI (Ozone Monitoring Instrument)	Aerosol & Ozone
Goddard Space Flight Center	OMI Surface UV algorithm	Surface Ultraviolet Irradiance

- g. Benefit to Society: Abate urban air pollution and facilitate the improvement and assessment of urban air quality.

### 2. Abstract

This Candidate Solution is based on using NASA Earth science research on atmospheric ozone and aerosols data as a means to predict and evaluate the effectiveness of photocatalytically created surfaces (building materials like glass, tile and cement) for air pollution mitigation purposes. When these surfaces are exposed to near UV light, organic molecules, like air pollutants and smog precursors, will degrade into environmentally friendly compounds. U.S. EPA (Environmental Protection Agency) is responsible for forecasting daily air quality by using the Air Quality Index (AQI) that is provided by AIRNow. EPA is partnered with AIRNow and is responsible for calculating the AQI for five major air pollutants that are regulated by the Clean Air Act. In this Solution, UV irradiance data acquired from the satellite mission Aura and the OMI Surface UV algorithm will be used to help understand both the efficacy and efficiency of the photocatalytic decomposition process these surfaces facilitate, and their ability to reduce air pollutants. Prediction models that estimate photocatalytic function do not exist. NASA UV irradiance data will enable this capability, so that air quality agencies that are run by state and local officials can develop and implement programs that utilize photocatalysis for urban air pollution control and, enable them to make effective decisions about air pollution protection programs.

### 3. Detailed Description of Candidate Solution

#### a. Purpose/Scope

This candidate solution examines use of NASA-derived atmospheric aerosol and ozone data to monitor UV dosage levels on the Earth's surface, and evaluate how this information would enhance the ability of decision makers to predict the efficiency of photocatalytically coated surfaces as a method for removing pollutants from urban air.

Within the framework of this candidate solution, the functional strategy is to look at novel methods for remediating environmental air pollution through the use of building construction materials made with photocatalytic materials, like titanium dioxide (TiO<sub>2</sub>). NASA UV irradiance data is then used to estimate the photocatalytic activity of these materials; this is important because the amount of UV can drive the photocatalysis process.

More than 75 percent of the U.S. population lives in urban communities where they are exposed to levels of smog or pollution that exceeds the EPA (U.S. Environmental Protection Agency) safety standards. Urban air quality presents a unique problem due to a number of complex variables, including traffic congestion energy production and energy consumption activities, all of which can contribute to and affect air pollution and air quality in this environment. In environmental engineering, photocatalysis is an area of research whose potential for environmental clean-up is rapidly developing popularity and success. Photocatalysis, a natural chemical process, is the acceleration of a photoreaction in the presence of a catalyst. Photocatalytic agents are activated when exposed to near UV (ultraviolet) light (320–400 nm) and water.

In recent years, researchers have expanded the applications of photocatalysis, and it has become more attractive for use because it is a non-invasive, non-toxic, and cost-effective method to address a wide variety of technologies related to purification and degradation processes (Choi, 2006; Cassar, 2004). Researchers have shown that building materials, like glass, tile, and cement, can be made or coated and with heterogeneous photocatalytic materials, like TiO<sub>2</sub> (Bonafous, 2006). Once created, these sidings, roofs, or roads could be used to remove outdoor air pollutants, such as nitrogen oxides, volatile organic compounds, carbon monoxide, and ozone. These pollutants are converted into non-toxic environmentally friendly compounds, such as carbon dioxide and water vapor. Large-scale deployment of these materials (e.g., by coating roadway systems) is being considered for air pollution mitigation (Wang, 2002) and has already been used on several building structures in Italy (Giussani, 2006; Povoledo, 2006). Additionally, these surfaces also exhibit a high affinity for water when exposed to UV light. Therefore, not only are the pollutants decomposed, but this superhydrophilic nature makes the surface self-cleaning, which helps to further increase the degradation rate by enabling rain and/or water to wash byproducts away.

The Clean Air Act, established by Congress in 1972 and amended in 1990 (EPA, 2007), is intended to protect the quality of our Nation's air. Congress also directed the EPA to set NAAQS (National Ambient Air Quality Standards) to regulate pollutants considered harmful to public health and the environment. Prevention and regulatory programs that are implemented are the responsibility of each individual state. To operate an air quality program, states must adopt and/or develop a plan and obtain approval from the EPA. Federal approval provides a means for the EPA to maintain consistency among different state programs and ensures that they comply with the requirements of the Clean Air Act. Even though pollutants have been regulated since the Clean Air Act was passed, many urban areas still have air pollution levels that exceed NAAQS.

To resolve this situation, alternative measures to abate persistent air pollution problems that exist in urban environments need to be explored. Such measures include examining cost-effective approaches to evaluate and address the environmental effects of energy production, use, and emissions as sources of pollution. For decades, human-induced air pollution, in particular smog has been strongly

associated with California. Technical innovations that involve photocatalytic degradation of organic air pollutants are being examined by LBNL, the EPA, and the State of California. The EPA is working with DOE's (Department of Energy's) LBNL (Lawrence Berkeley National Laboratory) to study the efficacy of titanium dioxide photocatalysis for removing air pollutants on community and regional scales. This research is being conducted under a Public Interest Energy Research Program Energy-Related Environmental Research grant titled Evaluation of Titanium Dioxide as a Catalyst for Removing Air Pollutants (PIER, 2006). The goal of this project is to establish the research, development, and implementation of a statewide program in California that uses surfaces coated with photocatalytic materials as a method for air pollution removal.

Working together, these groups are looking at creating and using construction materials that innately destroy pollutants in the air and that protect and prevent build-up of pollutants on surfaces, which additionally helps to preserve a structure's appearance over time (PIER, 2006). Preliminary testing among other groups using photocatalytic coatings on surfaces in urban settings have shown that some pollutants can be reduced anywhere from 20–70 percent (TXActive®, 2007).

b. Identified Partner(s)

A primary identified partner is the EPA. The EPA works with state and local government to identify requirements and to develop appropriate measures to ensure that air pollution programs meet requirements of the Clean Air Act. The EPA's Office of Air and Radiation (OAR) develops national programs, technical policies, and regulations for controlling air pollution and radiation exposure. Some of the areas that OAR is concerned with include pollution prevention and energy efficiency, outdoor air quality, industrial air pollution, and pollution from vehicles and engines. EPA partners with other federal agencies, state and local agencies, national organizations, private industry, and local communities to encourage voluntary and innovative methods to reduce air pollution. One of these partners is AIRNow. AIRNow is responsible for forecasting air quality by using the Air Quality Index (AQI), an index for reporting daily air quality. AQI indicates how clean or polluted regional air is, and what associated health effects might be of concern. AQI provides air quality conditions for over 300 cities across the US. EPA calculates the AQI for five major air pollutants regulated by the Clean Air Act: ground-level ozone, particle pollution (also known as particulate matter), carbon monoxide, sulfur dioxide, and nitrogen dioxide. For each of these pollutants, EPA has established national air quality standards to protect public health (AIRNow, 2007).

As mentioned in the previous section, the EPA is collaborating with LBNL to examine the use of photocatalysts in construction materials as an innovative way to minimize pollution in an urban environment. California is one of the world's largest economies and is the tenth largest energy consumer in the world. This process of generating and distributing energy has had detrimental impacts on air quality in California. As a result, smog, which is a combination of nitrogen oxides and hydrocarbons, has become one of California's biggest air quality problems.

Researchers at LBNL conduct the type of science that enables public policy-makers to make informed decisions about the most effective ways of reducing hazardous air pollutants. In 2005, the DOE LBNL was awarded a grant through the Environmental Exploratory Grant Program, which funds research on the relationship between energy use and air quality and on the health benefits of removing pollutants from urban air (PIER, 2006). The goal of this funded grant is to find new solutions to pollution problems that are not being resolved by emission reduction alone. This project incorporates multiple partners and researchers working together to evaluate the potential of photocatalytically coated building materials, such as walls and roofs, to remove pollutants from urban air. The findings will ultimately be shared with leading researchers and air quality agencies across the state, and future results could involve the establishment of statewide and/or nationwide programs for the research, development, and implementation of urban photocatalysis for urban air pollution control.

By partnering with NASA, historical and real-time UV data could be incorporated into LBNL's urban pollution mitigation project; this data would enhance the ability to assess the photocatalytic activity of these surfaces so that additional useful support could be provided to state and local decision makers. Further research on the UV photocatalytic degradation of building materials, as well as UV dosage in an urban canyon, are not fully understood and would require further investigation.

c. NASA Earth-science Research Results

Heritage data from the TOMS (Total Ozone Mapping Spectrometer) on the Nimbus 7, Meteor 3, and Earth Probe Missions, all specializing in ozone retrieval, could be used to develop long-term UV irradiance averages. This sensor, in conjunction with radiative transfer models, predicts daily global coverage of erythmal UV exposure, total column ozone, aerosol index, and reflectivity (GSFC, 2006). The latest TOMS is currently out of commission. Ozone and aerosol data is currently being provided by the OMI (Ozone Monitoring Instrument) on the Aura satellite that was launched in July 2004 into a near-polar, sun-synchronous orbit with a period of approximately 100 minutes. Aura repeats its ground track every 16 days to provide atmospheric measurements over virtually every point on the Earth in a repeatable pattern, permitting assessment of atmospheric phenomena changes in the same geographic locations throughout the life of the mission. The mission is designed for a 6-year lifetime. OMI observes Earth's backscatter solar radiation in the visible and UV with a wide-field telescope feeding two hyperspectral imaging systems. This sensor will add to the TOMS record of total ozone and other atmospheric parameters related to ozone chemistry and climate.

d. NASA Earth-Science Models

NASA-funded radiative transfer codes, such as the as the OMI Surface UV algorithm (Stammes, 2002), are used to estimate UV irradiance on the ground (Tanskanen et al, 2006a; 2006b) from satellite observations. These algorithms are relatively accurate for unobstructed surfaces. To predict the UV dosage within an urban environment, and in urban canyons in particular, these NASA Earth science results will have to be integrated into Monte Carlo or other ray trace radiative transfer approach to propagate the unobstructed radiation field to the Earth's surface.

e. Proposed Configuration's Measurements and Models

NASA historical and current UV, ozone, and aerosols datasets, along with radiative transfer models and biological activity functions, could be integrated into the assessment and evaluation of the overall effectiveness of photocatalytic degradation upon biological and chemical compounds. This integration would include the use of UV maps that would have activity response information pertaining to photocatalytic materials like  $\text{TiO}_2$ ; this information would be used to help understand and assess UV effects upon photocatalytic activity.

By partnering with the EPA and with the DOE's LBNL, NASA could provide historic and real-time UV data to help assess and evaluate if these photocatalytically created surfaces significantly reduce pollutants in urban environments, both at local and regional scales.

Further research, such as studying the interaction between  $\text{TiO}_2$  and assorted building materials as well understanding the effects of varying UV dosing is necessary. Also, urban canyon radiative transfer analysis needs to be incorporated. Additionally, time-dependent measurements require consideration, and large-scale/canyon effects warrant evaluation.

Because this type of ozone and aerosol data will have product continuity, life-cycle issues will probably need to address product changes, such as resolution and format. Such issues will result in some software changes and additional update of legacy systems.

#### 4. Programmatic and Societal Benefits

By partnering with the EPA and with the DOE's LBNL, NASA could help facilitate the research and implement a process that would enable the photocatalytic removal of urban air pollution not only to reduce air pollutants but also to improve air quality. This approach could shift the fundamental basis/dogmas associated with new building construction on a nationwide level.

By enhancing the quality of air in modern urban environments, NASA UV data with photocatalytic coatings would apply to the Air Quality and Public Health National Applications.

A test application designed as a future Rapid Prototyping Capability experiment would illuminate whether photocatalytically coated surfaces could be assessed for efficiency and effectiveness if additional UV data were considered when evaluating range and efficacy of this photocatalytic process.

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